Status of U.S. Harmful Algal Blooms: Progress towards a National Program

Harmful algal blooms kill coastal marine wildlife and poison humans.

National Oceanic and Atmospheric Administration

STATUS OF U.S. HARMFUL ALGAL BLOOMS: PROGRESS TOWARDS A NATIONAL PROGRAM

INTRODUCTION

U.S. coastal waters periodically experience extensive blooms of algae that impact living resources, local economies, and public health. This phenomenon is not unique to the U.S., but is global, with expanding problems in Scandinavia, western Europe, the Mediterranean, South America, Asia-Pacific islands, and other coastal nations. Increasingly frequent incidences and the serious impacts of some bloom events in the U.S. have led to an integrated, interagency HAB program that addresses needs for safeguarding public health, limiting bloom impacts on coastal resources, and developing the capability to predict when and where toxic blooms will occur.

Among the thousands of species of microscopic algae at the base of the marine food chain are a few dozen that produce toxins. Algal species make their presence known sometimes as a massive "bloom" of cells that may discolor the water (Figure 1). Other species, in dilute, inconspicuous concentrations of cells, are noticed because they produce highly potent toxins that either kill marine organisms directly, or transfer through the food chain, causing harm at multiple levels.

Blooms of toxic algae were commonly called "red tides," since, in the case of some dinoflagellates, the tiny organisms may increase in abundance until they dominate the planktonic community and tint the water reddish with their pigments. Because other blooms may tint the water bright green or adverse effects can occur when some algal concentrations are low and the water is clear, the scientific community now uses the term "harmful algal bloom" or HAB. This descriptor applies not only to toxic microscopic algae but also to nontoxic macroalgae (seaweeds) which can grow out of control and cause such ecological impacts as displacing indigenous species, altering habitat suitability, and depleting oxygen (Figure 2). HAB impacts include human illness and death from ingesting contaminated shellfish or fish, mass mortalities of wild and farmed fish, and alterations of marine food chains through adverse effects on eggs, young, and adult marine invertebrates (e.g., corals, sponges), sea turtles, seabirds, and mammals.

__Figure 1.__ Dense microalgal blooms can color the water bright green, red, or brown, and shade bottom plants and animals.

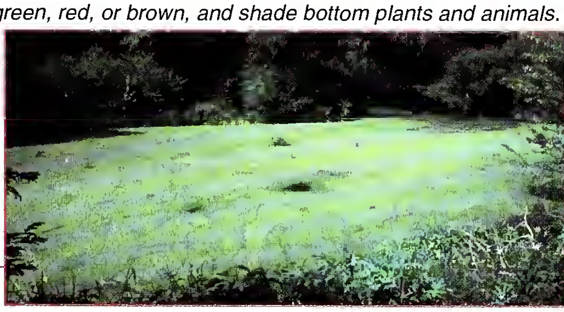


__Figure 2.__ Dense macroalgal blooms smother bottom plants and animals (e.g., corals and sponges) and may drift ashore.

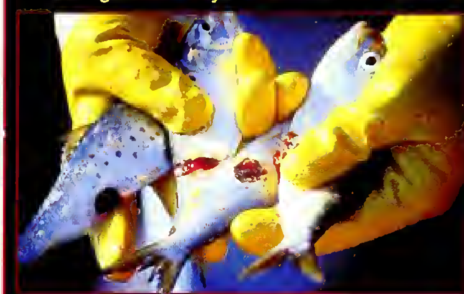
What is the problem?

Fish lesions, fish kills, irritating health problems for some Maryland Eastern Shore residents, and depressed commercial fish sales from the Chesapeake dominated last summer's local news media, capturing the at-

tention of state and federal agency officials. The cause—a microscopic, toxin-producing, single-celled dinoflagellate, *Pfiesteria*—was totally unexpected and appeared to catch politicians and agency officials off-guard. Public alarm resulted, partially because of the belief that this invisible predator was now lurking in the Chesapeake Bay.

"Ambush Predator"

One of several new species of "phantom" dinoflagellates, Pfiesteria piscicida, *has a complex life cycle (difficult-to-detect cysts, amoebae, nontoxic flagellates and toxic zoospore stages). Affecting human health and fisheries in mid- and southeastern U.S. estuaries, unknown substances freshly secreted by finfish stimulate* P. piscida *to produce several toxins that narcotize fish and cause the formation of open bleeding sores.*[1-4] *In the laboratory, human exposure to aerosols from toxic cultures has been linked to short- and long-term neurotoxic symptoms. Fishermen and others exposed to estuarine waters have also complained of similar problems, exemplified in the worst cases as a loss of neurocognitive ability from aerosolized toxin.*



Although these toxic cells were alarming and alien to local residents, HAB events are common along U.S. shorelines. HABs are now found throughout the U.S. coastal system, from the Gulf of Maine through the Gulf of Mexico and north to Alaska. Blooms of algae have been identified in every coastal state and HAB species regularly threaten coastal living resources, restrict local harvests of fish and shellfish, divert public funds to monitoring programs, depress local recreational and service industries, and burden medical facilities.

U.S. HABs are caused by a diverse group of organisms with serious impacts for humans and coastal ecosystems. When toxic algae are filtered from the water as food by shellfish such as clams, mussels, oysters, and scallops, shellfish tissues accumulate toxins.[5,6] Typically, shellfish are only marginally affected, even though a single clam can sometimes accumulate sufficient toxin to kill a human. Shellfish poisoning syndromes have been given the names paralytic (PSP), diarrhetic (DSP), neurotoxic (NSP), and amnesic (ASP) on the basis of descriptive human symptoms. Except for ASP, all are caused by biotoxins synthesized by marine dinoflagellates. ASP is produced by diatoms that, until recently, were all thought to be free of toxins and generally harmless.[7]

A fifth human illness, ciguatera fish poisoning (CFP) is caused by biotoxins produced by dinoflagellates that grow on seaweeds and other surfaces in coral reef communities.[8] Ciguatera toxins are transferred through the food chain from reef fishes that eat algae to the carnivores that feed on them (e.g., barracuda). Similarly, the viscera of commercially important fish (e.g., herring or sardines) can contain PSP toxins, endangering human health following consumption of whole fish. Whales, porpoises, manatees, seabirds, and other wildlife are victims as well, receiving toxins via contaminated zooplankton or fish (Figure 3).[9,10]

Impacts from other HABs occur when marine fauna are killed by algal species that release toxins and other compounds into the

Figure 3. *Toxins accumulated in tissues of small marine life that feed on HABs can kill large consumers like whales.*

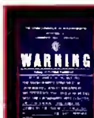
Figure 4. *Dense algal blooms may consume oxygen in the water column and cause massive mortalities of marine life.*

water, or that kill without toxins by physically damaging gills or by creating low oxygen conditions (Figure 4). *Pfiesteria* and related toxic species produce as yet unidentified toxins that have been implicated in temporary short-term losses of neurocognitive abilities (short-term memory) in Maryland residents exposed to water or aerosol containing the organism. Large, prolonged blooms alter the distribution of light, leading to decreasing densities of valuable submerged aquatic vegetation in our coastal areas and degrading nursery habitats. Dense accumulations of some HABs also lead to local depressions in oxygen levels (hypoxia and anoxia) that can reduce fish and shellfish habitat (e.g., seagrass, coral and sponge) and in most severe conditions, kill endemic fish and shellfish communities (Figure 4). Other HAB species can damage local shellfish and aquaculture fish stocks, resulting in severe economic hardship and, in some cases, collapse of the fishery (e.g., Long Island bay scallops).

What are the trends and economic consequences of HABs?

Documented episodes of PSP human intoxication and mortalities on the West Coast extend back to 1903 in California. PSP events were also common off Alaska, Oregon, Washington, and Alaska, but extended into Puget Sound only recently. On the East Coast, however, observations of PSP events prior to 1972 were limited to eastern Maine. Now, PSP has spread throughout the rest of New England and to Georges Bank. As far back as the mid-16th century, NSP toxins, which poison human consumers of shellfish, have caused respiratory irritation in humans and mortalities in fish and other wildlife in western Florida and Texas coastal waters, and occasionally were carried by the Gulf Stream to North Carolina. For the first time, Mississippi, Alabama, and Louisiana suffered an NSP outbreak in 1996. ASP toxins, which cause permanent loss of short-term memory and in some cases death, now occur along the West Coast and off Alaska, but the organism responsible for toxin production has also been identified from northern Gulf of Mexico and Massachusetts waters. Ciguatera poisoning is the most prevalent HAB intoxication in tropical and subtropical U.S. possessions, affecting as much as 50% of the U.S. Virgin Islands population, as well as many residents and tourists of other tropical U.S. states and territo-

Paralytic Shellfish Poisoning



PSP syndrome is life-threatening and can result in respiratory arrest within 24 hours of consuming shellfish laced with toxins from feeding on algae in the genus Alexandrium. *There is no antidote. PSP health risks are controlled by monitoring shellfish and rapidly closing toxic regions. PSP toxins can be transferred through the food chain, killing fish, birds, and marine mammals.[10-12] Before 1972, PSP on the U.S. Atlantic coast was restricted to eastern Maine. Now the entire New England coastline experiences periodic PSP outbreaks with extensive shellfish bed closures and economic losses. Similarly, PSP appeared in Puget Sound in the late 1970's. PSP impacts more U.S. coastline than any other HAB.[13]*

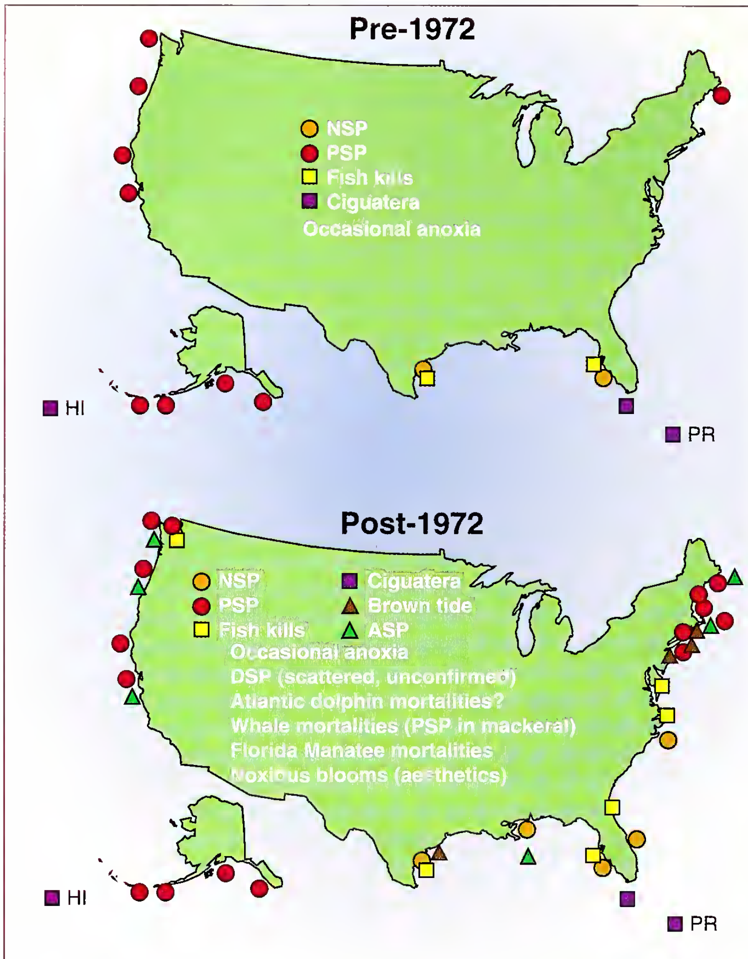


Figure 5. *Since 1972, U.S. HAB distribution appears to be expanding and events occurring more commonly.*

ries.[14] On this evidence, the experts conclude that HAB problems are increasing throughout U.S. coastal waters (Figure 5).

The scale of HAB economic impacts is startling, and, if the trend continues, the future most likely holds economic hardships for many more local communities that depend on healthy fish and shellfish resources. The rapid geographic expansion in the past two decades is responsible for economic losses approximating $100 million per year. This estimate would significantly increase if shellfisheries that have never opened due to continuous toxin accumulation were included in computations. For example, PSP in shellfish along Alaska's 30,000 mile coastline has prevented development of a commercial shellfishery in the state, estimated at $50 million annually.[15] Domoic acid intoxication of razor clams and Dungeness crabs in Washington and Oregon resulted in losses of $15-20 million in 1991, associated with collapse of the recreational and commercial fisheries and a huge tourist industry. Farmed fish have also been impacted as a result of mortalities caused by *Chaetoceros convolutus* and *Heterosigma carterae*, with 1987 losses of $0.5 and $4-5 million, respectively.[16, 17]

Along these same lines, a single PSP event in Maine in 1980 reportedly cost the state $7 million[18] and outbreaks have recurred nearly every year since. Similarly, the bay scallop fishery in Long Island, yielding $2 million annually, has never recovered from blooms of the brown tide organism *Aureococcus* in 1985.[19] *Pfiesteria* events in August, 1997 along Maryland's Eastern Shore resulted in an estimated $40 million loss in commercial sales for the Chesapeake region.[20] In the Gulf of Mexico and along the western coast of Florida, *G. breve* blooms nearly every year, with estimated losses of $20 million per event.[21] In coastal North Carolina, 400 km of shellfish area were closed from the same organism at a loss of $25 million in 1987-88[22] and the shellfisheries of four states along the northern Gulf of Mexico (Florida, Alabama, Mississippi and Louisiana) were closed in 1996, exceeding $15 million in lost revenue.[23]

Noneconomic losses accompanying U.S. HAB events have also been dramatic. For example, 149 manatees, an endangered

species, were killed off western Florida in a 1996 *G. breve* bloom. Each year, fish, bottlenose dolphins, whales, sea turtles and birds succumb from encounters with U.S. HABs (Figure 6). Such events often trigger public outcry and a demand for immediate remedial action.

Figure 6. *Losses of wildlife from ingestion of HAB toxins are significant and include this dead pelican and these manatees.*

What causes HABs to increase?

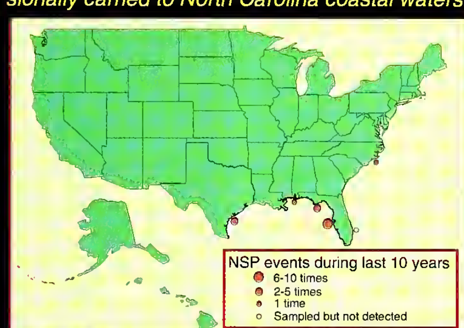
Although few would argue that the number of toxic blooms, the economic losses from them, the types of resources affected, and the number of toxins and toxic species have all increased dramatically in recent years in the U.S. and around the world, opinions differ with respect to the reasons for this expansion.[24-26] We may have contributed to the global HAB expansion by transporting toxic species in ship ballast water[27] or by dramatically increasing aquaculture activities. Other "new" bloom events may reflect indigenous populations that were discovered because of better detection methods and more observers.[29] The linkage to pollution, however, cannot be ignored. Increased nutrient loads to coastal waters may stimulate background (i.e., relatively low level) populations of microscopic and macroscopic algae to initiate a bloom. Some scientists even argue that the nutrients that humans supply to coastal waters are delivered in proportions that differ from naturally occurring ratios, such that we may be altering algal species composition by favoring certain groups (e.g., HABs) better adapted to altered nutrient supply ratios.[30] *Pfiesteria,* for example, seems to thrive in polluted waters.[31]

A U.S. INTERAGENCY HAB PROGRAM

Until recently, the U.S. had no national program or plan to attack problems associated with HABs and marine biotoxins, despite a long history of impacts, research, and local monitoring. Research programs were small, fragmented, and uncoordinated, run by individual investigators and rarely have been sustained through time. There was little communication between workers and no federal coordination of activities with respect to national priorities. In contrast, other countries such as Canada, France, and Japan established coordinated national research programs that included frequent meetings of investigators, sustained fund-

Neurotoxic Shellfish Poisoning

NSP gastrointestinal and neurological symptoms from eating shellfish that have fed on toxic Gymnodinium breve *dinoflagellates, can be debilitating.*[22, 28] *There is no antidote; full recovery usually is within days. Monitoring programs generally prevent human exposure except in previously unaffected areas where officials may not be monitoring. During blooms, humans may be driven from coastal areas by asthma-like symptoms from rotting fish and toxic aerosols. Blooms occur annually along Gulf of Mexico shores (e.g., 22 of the last 23 years off western Florida), can cover as much as* $3x10^4$ *km,*^{2} *and can last as long as 18 months. In 1996, Louisiana, Mississippi, and Alabama experienced their first bloom—30 bottlenose dolphins were killed and the oyster industry suffered extensive economic loss. A 1997 Texas bloom killed over 14 million fish. Blooms are occasionally carried to North Carolina coastal waters.*



ing in high priority areas, and continual re-evaluation of progress and priorities for the future. This situation has begun to change in the U.S. If the effort is sustained, elements of a national program on HABs are being implemented at a scale that will surely have a significant impact on understanding these phenomena and our ability to manage their impacts.

How has the U.S. responded to HAB events?

Agency and academic research laboratories have been active for the past several years, primarily focusing on HAB effects on fish habitat and nutrition. This research generated a substantial expertise and knowledge for the diverse suite of HAB species in the U.S., but there was no coordinated approach to developing explanations for HAB problems nationwide.

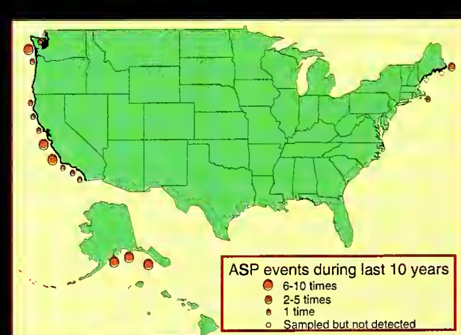
Convinced that HAB prevalences and impacts were increasing, U.S. researchers, agency representatives, and members of the private sector began a series of workshops at the start of this decade to plan a national response. Intense and productive workshops over the last 5 years yielded a comprehensive national HAB program outlined in three separate reports. The first, a general approach to HABs outlined in the Department of Commerce's National Oceanic and Atmospheric Administration (DOC/NOAA) sponsored report *Marine biotoxins and harmful algae: A national plan*[32] is the nation's foundation for HAB research, management, and policy.

The second report—*ECOHAB The ecology and oceanography of harmful algal blooms a national research agenda*[14]—is sponsored by NOAA and the National Science Foundation (NSF). It is a focused expansion of *National Plan* objectives pertaining to the ecology, physiology and oceanography of bloom-forming species. This report is now the blueprint for ECOHAB, the first Federal research program on the ecology and oceanography of HABs. ECOHAB is supported by DOC/NOAA, NSF, the U.S. Environmental Protection Agency (EPA), Department of Defense's Office of Naval Research (ONR), National Aeronautics and Space Administration (NASA), and the U.S. Department of Agriculture (USDA). ECOHAB research, focused on the mechanisms responsible for HABs in U.S. coastal waters, will be used to develop predictive models for HAB events. Such models will help guide future regional and national agency responses to protect citizens, businesses, and coastal living resources from HABs.

The third portion of the U.S. HAB program is summarized in a report that focuses on processes, mechanisms, and technologies that might be employed in the control of HABs and their impacts. NOAA and the National Fish and Wildlife Foundation supported development of *Harmful algal blooms in coastal waters: Options for prevention, control and mitigation*.[13] It too was derived from

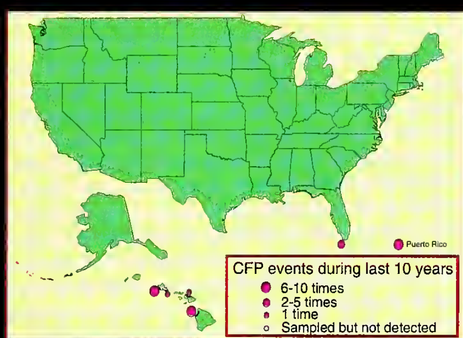
Amnesic Shellfish Poisoning

ASP, so named because one of its most severe symptoms is the permanent loss of short-term memory, can be fatal. The ASP toxin, domoic acid, is produced by the diatoms, Pseudo-nitzschia multiseries *and* P. australis. *First identified in eastern Canada in 1987,*[3] *it has been a problem for the U.S. Pacific coast states since 1991.*[33] *Domoic acid has been detected in shellfish on the east coast as well and toxic* P. multiseries *cells have been isolated from Gulf of Mexico water. Besides shellfish, it is now known that domoic acid also accumulates in fish and in crab viscera.*



Ciguatera Fish Poisoning

CFP is a malady associated with dinoflagellate toxins that accumulated in tropical fish flesh. Although the most frequently reported non-bacterial illness associated with eating fish in the U.S. and its territories, the number of CFP cases is probably far higher, because there is no confirmatory laboratory test and reporting to the U.S. Center for Disease Control is voluntary.[28] *CFP is produced primarily by epiphytic dinoflagellates (e.g.,* Gambierdiscus toxicus, Amphidinium carterae, Coolia monotis *and several others in the genera* Prorocentrum, Ostreopsis *and* Thecadinum*) growing on the surfaces of red and brown macroalgae in virtually all sub-tropical to tropical U.S. waters. When macroalgae are grazed by herbivorous fish, ciguatera precursors in the epiphytes are biotransformed into ciguatoxin in fish flesh. Ciguatoxin accumulates, persists over extended periods and, if consumed by humans, causes long-term, debilitating, but non-lethal illness.*[34, 35]



objectives of the *National Plan* but defines an area that the U.S. had not yet dealt effectively with in its responses to HABs (i.e., management and control). The U.S. is far behind many parts of the world in managing coastal waters to limit HAB impacts. For example, Japan, China, and Korea are exploring a suite of technologies and strategies (e.g., clay flocculation, algicidal bacteria) to directly eliminate blooms in their territorial waters.[36] This report is now the basis of a new U.S. initiative to manage bloom development, persistence, and toxicity, thereby minimizing economic and ecologic impacts.

These three reports are the U.S. framework for an integrated national HAB program. Guidance, direction, and support for the U.S. program is provided in biannual meetings of the *Ad Hoc* Interagency Task Force on Marine Biotoxins and Harmful Algae, composed of agency representatives and academic researchers. Although individual Federal agencies maintain agency-specific HAB projects, NOAA's Coastal Ocean Program (COP) is taking the lead in guiding initial portions of the national effort through coordination of the U.S. research program ECOHAB and is attempting to identify and interface HAB activities across the agencies. In its infancy, this activity is receiving support from all agencies with initial cooperation and dialog evident among the ECOHAB partners, the Department of Interior's U.S. Geological Survey (USGS), as well as the agencies responsible for public health and seafood safety, the Food and Drug Administration (FDA), the National Institute of Environmental Health Sciences (NIEHS), and the Center for Disease Control and Protection (CDCP) in Human Health Services.

Additional input to the national program is also ensured through operation of the National Office of Marine Biotoxins and Harmful Algal Blooms, located in Woods Hole, Massachusetts. This office, supported by NOAA and NSF, was established in response to a national need for timely HAB information and coordination. The office distributes national and international HAB information to researchers, managers, and public officials through its active web site. Further, the office assists the national effort by overseeing national workshops and symposia on HAB-related topics. Overseen by Dr. Donald Anderson, a HAB research scientist and U.S. representative to many international organizations, the National Office is critical to continued HAB activities nationwide.

How effective are current HAB efforts?

Research on toxins, toxic species, new detection methods. Current research is focused on some of the most troublesome HAB

species impacting coastal areas (Appendix 1). The initial interagency ECOHAB projects are in place and funded beginning in the fall of 1997. Two intensive, five-year multi-disciplinary research programs are supported for toxic *Alexandrium* in the Gulf of Maine and *Gymnodinium* in the Gulf of Mexico, yielding predictive models for forecasting landfall of the HAB species. Seven other targeted studies are also supported, addressing macroalgal blooms in Guam, trophic impacts of several U.S. HAB species (*Alexandrium*, *Gyrodinium*, *Prorocentrum*, *Pseudo-nitzschia*), population genetics of brown tide populations from Long Island, bacterial control of toxic *Gymnodinium*, and nutrient requirements of ASP-producing *Pseudo-nitzschia*. A second funding opportunity for new research on *Pfiesteria* and other HABs was published this spring with awards scheduled for this summer. Blooms of brown tide populations that have decimated bay scallops and seagrasses in Long Island are being intensively examined through a Brown Tide Research Initiative (BTRI), supported by NOAA's COP. The NOAA Sea Grant Program is supporting individual HAB projects throughout the U.S. that include toxic species such as *Pfiesteria, Alexandrium,* and *Prorocentrum.*

Pfiesteria's toxins are being intensively investigated through NOAA and NIEHS support of the Charleston Laboratory and the University of Miami's Marine and Freshwater Biomedical Science Center. Identification, purification, and assay development are imminent. FDA is conducting research on the culture of pfiesterioid organisms for characterization, toxin production, and development of detection methods. Nutrient requirements and trophic impacts of *Pfiesteria*-related species are part of an intramural research program at NOAA's Beaufort Laboratory. The linkages between proliferation of coastal HABs with land use and watershed characteristics are key components of intramural EPA, USDA, and USGS research programs. The economic impacts of HABs, a critical indicator of societal influences on the initiation of HAB events, are being summarized by the National Office of Marine Biotoxins and Harmful Algal Blooms with support from NOAA Sea Grant. Epidemiology, symptomology, diagnoses, therapy, and advisory information for humans exposed to marine biotoxins are major initiatives within the CDCP. And finally, development of toxin biomarkers, indicators, and exposure thresholds are expanding programs within the CDCP and NIEHS.

National Plan ob-

Brown Tide Blooms

BTBs, caused by golden-brown algae, recently appeared off southern New England and Texas. A massive bloom of Aureococcus anophagefferens *was first reported in the bays of eastern Long Island, New York, in June of 1985. Severe brown tides have occurred in most years since then and now are also in Barnegat Bay, New Jersey, and Narragansett Bay, Rhode Island. After a drought that increased the salinity and severe freezes that killed millions of finfish in Laguna Madre, TX, an extensive bloom of a new species, Aureoumbra lagunensis, appeared in 1990 and each summer since. Both BTBs have had substantial ecological impacts (e.g., reductions in zooplankton grazing rates, decreased light penetration and reductions in the extent of seagrass beds). Submerged aquatic vegetation has been decimated in both regions due to BTB shading. Subtle ecosystem changes from long-term dominance of the Laguna Madre system in southern Texas are likely.[37] BTBs have caused mass mortalities of blue mussels in Rhode Island.[38] In Long Island Sound, BTBs have had a severe impact on commercially valuable shellfish, affecting more than 80% of New York's bay scallop harvest.[39]*

Harmful Cyanobacterial Blooms

Excessive growths of Anabaena, Aphanizomenon, *and* Microcystis, *can lead to HCBs that exhibit severe neuro-, cyto- and hepatotoxicity in a variety of mammals (e.g., humans and farm animals), birds, fish and invertebrates (e.g., zooplankton). HCBs are national economic and environmental threats, occurring in large estuarine systems (e.g., Chesapeake Bay, Albemarle-Pamlico Sound and Florida Bay) and the Great Lakes. For example, a persistent algal bloom dominated by a new HCB species,* Synechococcus elongatus, *appeared in 1991 in mid-north central Florida Bay, spread to central and western areas, and persists more or less to this day. This HCB and the turbid waters and reduced light penetration it causes have been implicated in large-scale mortalities of seagrass and sponge beds and even degradation of Florida Keys coral reefs.*

jectives specific to toxin identification, characterization, human health, and assay development are current activities of CDCP, NIEHS, and laboratories in NOAA and the FDA. The NIEHS Marine and Freshwater Biomedical Science Centers have dedicated missions for marine biotoxin research within each university center in the NIEHS program receiving annual support. The University of Miami NIEHS Marine and Freshwater Biomedical Sciences Center is an internationally respected resource for several toxins, including the brevetoxins, fatal to endangered manatees and sea turtles. The Center's staff is currently focusing on identification of and assay development for *Pfiesteria* toxins. NOAA's Charleston Laboratory and the Northwest Fisheries Science Center are investigating toxin production and living resource indicators to toxin exposure for several U.S. HAB species. NOAA's National Environmental Satellite and Data Information Service (NESDIS) is purchasing, processing, and providing ocean color satellite data and products in near-real time that should be helpful in detecting and monitoring HABs. In cooperation with COP, NESDIS is currently developing regionally specific ocean color algorithms and calibrating/validating incoming and outgoing data streams for HAB detection (e.g., *G. breve* for the west Florida shelf and *Alexandrium* for the Gulf of Maine).

CDCP and NIEHS were active partners in resolving public health issues for Maryland in 1997. Through such efforts, CDCP-state partnerships expand epidemiological studies on marine biotoxins and develop case histories, diagnoses, therapies, and advisory information for public officials and the health community.

Because of its mandate to ensure food safety, FDA maintains a strong research and response capability to detect, evaluate, and mitigate toxic events which could affect food. FDA research on seafood toxins (freshwater and marine) is carried out at dedicated seafood laboratories located in Washington, D.C. Dauphin Island, Alabama, and Bothell, Washington. These laboratories culture toxic organisms, isolate, and characterize toxins, develop methods, supply toxin standards, and evaluate risks from toxin exposure. When outbreaks occur, these laboratories analyze samples from cases of suspected seafood poisoning. Illnesses from shellfish toxins (PSP and NSP) and ciguatera have been confirmed from several poisonings over the past two years. FDA laboratories aid states when emergency needs for environmental analyses arise that exceed state capabilities (e.g., the Gulf of Mexico NSP outbreaks of 1996). FDA experts in seafood toxins work with state and federal officials to determine the extent and hazard from environmental occurrences of familiar (e.g., PSP) or less familiar

Diarrhetic Shellfish Poisoning

DSP is considered by some scientists to be the most common and globally widespread phytoplankton-related seafood illness. DSP-producing species of phytoplankton such as Dinophysis acuminata *and* Prorocentrum lima *occur throughout all temperate coastal waters of the U.S. The first confirmed incidence of DSP in North America occurred in 1990 and 1992 in Canada. DSP, attributable to* P. lima, *has been reported from northern Maine and from Georges Bank, but generally is not a problem in the U.S.*

toxic events (e.g., the response to the suspected *Pfiesteria* species events in Maryland last year). A major undertaking of the FDA Washington Seafood Laboratory is the training of state and foreign officials to establish observer programs which provide early warning of potential HAB events. FDA toxin experts represent the U.S. in several international organizations (e.g., APEC, the Asian Pacific Economic Cooperative) with goals for the global distribution of safe seafood.

Monitoring and assessment capabilities. Other current HAB activities in the Federal government address the *National Plan* objectives focusing on rapid response and assessment capabilities to toxic and HAB outbreaks. The unprecedented mass mortalities of fish, high incidence of fish with lesions, and public illness associated with toxic *Pfiesteria*-like populations in Maryland's Eastern Shore tributaries this past summer initiated an immediate Federal-state partnership to vigorously monitor and assess watershed conditions, public health, and seafood safety for the region. An immediate NOAA and EPA allocation of funds resulted in an enhanced and expanded water quality monitoring program by Maryland's Department of Natural Resources with cell identification and toxicity determined at North Carolina State University (Figure 7) and Florida Marine Research Institute laboratories. A NOAA vessel and captain were stationed on the river for the summer. The NOAA-State Cooperative Oxford Laboratory and USGS were instrumental in assessing pathology of lesioned and dead fish as well as coordinating fish bioassays in the Pocomoke River. CDCP and NIEHS assisted Maryland's health teams in conducting public health surveys and clinical examinations of *Pfiesteria*-exposed and non-exposed individuals. NIEHS, USDA, NOAA's Sea Grant, and EPA supported workshops specific to *Pfiesteria*, its toxins, and impacts. The FDA immediately initiated short-term bioassays of *Pfiesteria*-exposed fish and shellfish to safeguard seafood from the area. NOAA's Maryland Sea Grant office produced a web site for near real-time distribution of information from the tributaries, laboratories, and public officials.

This immediate, multi-agency response, admittedly *ad hoc*, served to consolidate support from individual agencies that a rapid response capability was a national need for comparable events in the future and became one of the primary recommendations for an interagency report to the White House providing recommendations for future HAB programs in the U.S. Seven agencies (Department of Interior [DOI], DOC/NOAA, CDCP, FDA, USDA, EPA, and NIEHS) participated to produce *National harmful algal bloom research and monitoring strategy: An initial focus on Pfiesteria, fish lesions, fish kills, and public health*, providing the basis for planning Federal activities and responses for similar events in the future. *National Plan* objectives are focused and, with little revision,

were the model for developing this HAB Strategy.

The successes of the Federal-State partnership in rapidly responding to Maryland's *Pfiesteria*-induced fish kills and public illnesses have also resulted in additional support in FY98 to ensure a similar capability in the coming year. NOAA and EPA each received funding for assisting State programs for *Pfiesteria* monitoring and assessment beginning this spring. Following a meeting with mid- and south Atlantic state representatives, Federal-State partnerships will be formed through distribution of Federal funds to individual states for supplemental program assistance and the expansion of selected program elements.

Access to databases and information communication. The identification of databases on bloom incidences, toxin occurrence in shellfish, mass mortality events, epidemiology, and the dissemination of this information is a key *National Plan* objective. As noted above, the National Office of Marine Biotoxins and Harmful Algal Blooms has a HAB-dedicated web site for distribution of all national and international HAB material. Most Federal agencies also maintain web sites for distributing agency-specific information and in the last several years, electronic linkages to HAB web pages have been a focus of several Federal organizations. For example, NOAA's

Figure 7. *This North Carolina State University researcher is one of a few HAB scientists studying toxic* Pfiesteria *cells.*

HAB Fish Kills

Catastrophic losses of cultured and wild fish not only occur from many toxic algal species, but also from others that do not cause illnesses in humans. Blooms of the diatom, Chaetoceros convolutus, *do not produce a toxin but have caused massive fish kills. Chains of these cells armed with long setae and short secondary spines become lodged in fish gills and cause blood hypoxia as a result of mucous production. Blooms of the flagellate,* Heterosigma carterae, *have caused even more extensive farmed-fish mortalities in British Columbia and Washington state with substantial economic losses for this industry.*

Maryland, North Carolina and Virginia Sea Grant Offices encouraged the public to use their HAB web sites and provided additional advisory information during the recent *Pfiesteria* outbreaks. These Sea Grant Offices as well as others in Mississippi and New York have featured newsletters dedicated to HABs to inform the research communities and educate the public on HAB threats in local regions. NIEHS Centers also distribute results through web sites. Further, community participation in HAB workshops is also increasing, largely through NOAA, NIEHS, USDA, NSF, and EPA support. The same agencies are identifying HAB-related databases, another *National Plan* objective, for community access and revision.

Future HAB activity support. Congressional appropriations in FY 1998 and the President's proposal for 1999 will strengthen and enhance critical capabilities to provide comprehensive research, monitoring, assessment, planning, as well as scientific and technical support to states and communities (Figure 7). One of the greatest threats to U.S. coastal areas—nonpoint source pollution, in-

Federal FY 98-99 Support for U.S. HAB Activities								
National Plan Objectives	NOAA	CDC	FDA	EPA	NSF	NIEHS	USDA	DOI
1. Isolate, characterize toxins—FY1998	400K	500K	400K	400K		300K		
FY 1999 resources	400K	500K	400K	250K		300K	200K	
2. HAB detection methods—FY 1998	300K	1500K	400K	400K	150K		32K	100K
FY 1998 resources	300K	1500K	300K	400K	150K		300K	300K
3. Toxin effects on ecosystems/humans—FY 1998	700K	5000K	700K	650K	120K	350K	40K	
FY 1999 resources	1700K	5000K	700K	950K		350K	500K	
4. Forecasting capabilities—FY 1998	2200K		400K	300K	682K			
FY1999 resources	3400K		400K	500K	572K			
5. Management and mitigation—FY 1998	500K		700K	700K				
FY 1999 resources	1000K		700K	500K			1000K	
6. Rapid response to HABs—FY 1998	500K	2000K	700K	800K				100K
FY 1999 resources	2200K	2000K	700K					100K
7. Communication, outreach, education—FY 1998	300K	1000K	500K	2K				
FY 1999 resources	300K	1000K	500K	10K				
8. Databases—FY 1998	400K		400K		100K			100K
FY 1999 resources	800K		400K		100K			100K
TOTAL FY 1998	5.30M	10.00M	4.20M	3.52M	1.05M	0.65M	0.72M	0.30M
TOTAL FY 1999	10.10M	10.00M	4.20M	2.61M	0.82M	0.65M	2.00M	0.50M

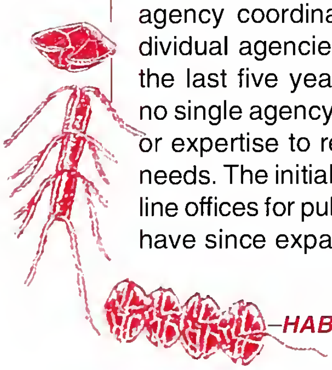
Table 1. *Federal agency FY 1998 funding and proposed FY 1999 support for harmful algal bloom research, monitoring and assessment activities in U.S. coastal waters.*

creasingly frequent outbreaks of harmful algal blooms, and other symptoms of degraded coastal ecosystems that adversely impact coastal economies—will be efficiently and effectively addressed. Agency partners will continue participating in the multiagency National *Pfiesteria* Research and Monitoring Strategy and ECOHAB, as well as provide grants to states, universities, and communities to conduct monitoring and rapid assessments in response to *Pfiesteria* and other HAB outbreaks.

What is the future for a U.S. Interagency HAB Program?

Although this summary of current activities suggests that the U.S. has a strong and active national HAB program, the program is just beginning. Commitment to multiagency coordination of HAB activities by individual agencies has occurred only during the last five years, after each realized that no single agency possessed either the funds or expertise to respond to the suite of HAB needs. The initial partnerships among NOAA line offices for publication of the *National Plan* have since expanded to 3-agency sponsorship of ECOHAB research projects, then 7 agencies helped draft the *National Strategy* in response to the recent *Pfiesteria* crisis. With such interagency commitment, an integrated, interagency Algal Bloom Program may become a reality in the near future.

With the goal of developing a predictive modeling capability for HABs in all U.S. coastal waters (i.e., HAB predictions like coastal weather forecasts), ECOHAB research must rigorously investigate and then model growth and toxin dynamics of the 7-8 toxic species and regions along the entire U.S. coast. Five-year ECOHAB research projects have just begun on two toxic species and regions, *Alexandrium* in the Gulf of Maine and *Gymnodinium* in the Gulf of Mexico. The remainder of the coastline and other HAB species need investigation. Research is needed on brown tide populations in Long Island Sound and off Texas, *Pfiesteria* in mid- and south Atlantic states, macroalgal blooms in Florida's and Hawaii's coral reefs, ciguatera dinoflagellates in sub-tropical and tropical U.S. possessions, *Pseudo-nitzschia* in the northwestern Gulf of Mexico and along the west coast, and *Chaetoceros* and *Heterosigma* in the northwest. These efforts will be the focus of future ECOHAB research

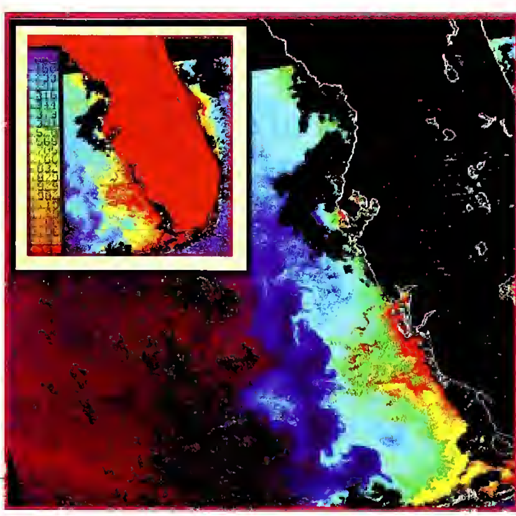


activities.

A critical area in need of major support that was identified in the *National Plan* and the recent *National Strategy* for *Pfiesteria* is better understanding of toxin impacts, both acute and chronic, on coastal resources and humans. This includes identification of the toxins and toxic cells in water and tissues; development of rapid, reliable, and inexpensive assays for their field detection; identification of biomarkers for monitoring HAB toxins in wildlife and humans; and establishment of exposure thresholds for toxicity. Additionally, development of the medical expertise specific to toxins, toxicology, and treatment should be addressed. Although some of this effort is already underway at the NIEHS Centers for research, the CDCP, a USGS laboratory, an FDA laboratory, and two NOAA laboratories, an expanded intra- and extramural program is needed to gain baseline information quickly on such complex topics.

Reducing HAB impacts is a major emphasis for the emerging national HAB program. The *National Plan* objective to pursue prevention, control and mitigation options for our increasing HAB problem is a critical need. As HABs continue to increase, we must refocus our goals and research expertise toward developing techniques for detecting and ameliorating the impacts of these natural disasters (Figure 8).

Figure 8. *Enhanced color satellite imagery is one of several tools being refined to detect and track HABs.*



Finally, there are strong indications that human activities in watersheds of coastal tributaries may be directly linked to the increasing prevalence and impacts of several HAB species. This implies that coastal eutrophication (excess nutrient loads), increased frequency of HAB events, and reduced oxygen levels in water (e.g., hypoxia and anoxia in the "dead zone" in the Gulf of Mexico) may all be interrelated. There has been an increasing emphasis and coordination among DOC/NOAA, EPA, USDA, and DOI to enhance research capacities in these areas. This comprehensive national approach to nutrient inputs and coastal ecosystem responses resulted in a major focus of the recent Clean Water Action Plan being the reduction of excess nutrients from nonpoint sources of pollution, particularly in coastal areas.

SUMMARY

The U.S. has in place a national HAB program arising from the framework provided by the three focused HAB reports prepared during the past five years. These reports are the basis for 1) the integrated, multi-agency national research program, ECOHAB, 2) a focused partnership between CDCP and NIEHS to significantly expand our capacity to respond to human health concerns from marine biotoxins produced by coastal HABs, and 3) a developing interagency HAB management program. The Federal government has initiated a rapid assessment capability to assist states and regions impacted by unexpected HAB outbreaks. Attention to linkages between human activities on the land and bloom outbreaks in receiving waters is a renewed focus for several agencies (i.e., DOC/NOAA, EPA, USDA, and DOI). The U.S. HAB science community is vigorously responding to the need for toxin and HAB detection methods to provide field assays for most of our algal toxins

in the near future. Safe seafood for our society is ensured through the continuous toxin monitoring and bioassay operations coordinated by the FDA.

Although much remains to be done there is a firm base provided by our national expertise and technologies. The future is full of new challenges in HAB research, monitoring, assessment, and prediction. The Federal agencies are committed to sustaining their national effort to ensure healthy living resources, seafood safety, and sustained economic development in regions impacted by HABs.

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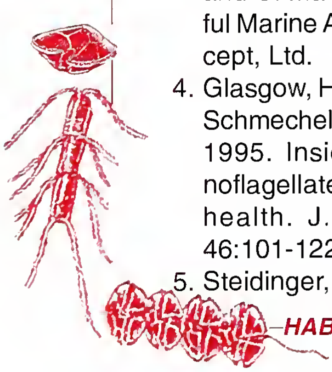

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APPENDIX 1

Federal HAB-related Projects/Programs. Numerous projects/programs related to HABs are underway in Federal offices and laboratories; descriptions of primary HAB efforts follow.

DOC/NOAA

Coastal Ocean Program (COP) is coordinating the competitive, federal, interagency research program, ECOHAB, implemented to determine environmental factors and cellular mechanisms responsible for HAB events in U.S. coastal waters. This partnership of DOC/NOAA, NSF, EPA, USDA and ONR, is focused on identification of those factors favoring growth and accumulation of HAB species in order to develop predictive models for forecasting bloom events. ECOHAB's multi-disciplinary, long-term projects link circulation of specific systems with the ecophysiology of individual taxa, yielding a biophysical description of bloom formation, termination and toxicology. Presently, two regional blooms are being examined (Gulf of Maine and the Gulf of Mexico), leaving approximately two-thirds of the U.S. coastline and the associated algal blooms to be addressed in future ECOHAB projects. COP, in partnership with EPA, also drafted the *National Strategy*. Further, COP sponsored the comprehensive report on prevention, control and mitigation of HABs, developed this Congressional report, and provides financial sup-

Figure 9. *The basis for a U.S. HAB coastal research program.*

port for the National HAB Office and the International Oceanographic Commission's (IOC) *HA News* (an international newsletter on HABs). COP represents the U.S. on the IOC Intergovernmental Panel on Harmful Algal Blooms and the APEC Marine Resource Conservation Working Group, and actively works in establishing bilateral HAB agreements with its international partners.

Sea Grant Program. With its role in marine research, education, advisory services and public outreach, Sea Grant expertise and its network of local experts plays a major role during HAB events. Sea Grant has long supported individual investigators studying local HAB problems (e.g., research first identifying *Pfiesteria* in North Carolina) and this support has built the foundation for several of the large regional HAB field projects. A series of articles recently published by Maryland Sea Grant (e.g., *In Harm's Way? The Threat of Toxic Algae; Harmful Algal Blooms on the Move*; and *The Trouble with Toxics in the Bay*) explained to readers the latest information on algal blooms, particularly those in the Chesapeake Bay region and the role of the complex of *Pfiesteria*-like organisms in fish mortalities in the Pocomoke River. Sea Grant programs in Maine, Massachusetts, New York, Florida, Texas, Washington, North Carolina, and Alaska have released similar materials on HABs from those areas of the country. Sea Grant workshops in Maryland and North Carolina on *Pfiesteria* problems were instrumental in easing public concerns over the threat from this harmful dinoflagellate.

NOAA laboratories (at Charleston, Beaufort, Oxford, Great Lakes, and Seattle) conduct research on coastal HABs and their impacts. Charleston's HAB research focuses on structural chemistry, biochemistry, toxicology and phycology of PSP, NSP, ASP, DSP, ciguatera and *Pfiesteria* toxins. Highlights include toxin purification and methods for detecting toxins in seafood and environmental samples (e.g., cell-based receptor and reporter gene assays), and research on molecular mechanisms controlling growth in dinoflagellates, the role of bacteria in bloom dynamics and toxin production and effects of algal toxins on reproductive health of fisheries species. Beaufort, with expertise in culturing toxic phytoplankton and assessing the ramifications of biotoxins in marine food webs,[40] has been actively involved in *G. breve* research since 1987 and now *Pfiesteria*. Highlights include a new technique for brevetoxin determination (sensitive capillary electrophoresis with laser detection), a feasibility study on the use of phytoplankton pigments and absorption spectra as potential biomarkers for *G. breve*, calibrating data and calculating algorithms for the Sea WiFS ocean-color satellite sensor for monitoring HABs. Oxford Lab is a center of expertise for invertebrate pathology and marine fish diseases with numerous publications (e.g., a *Manual on Histologic Techniques*, a standard for processing fish and shellfish, and the *Registry of Marine Pathology* cataloguing fish diseases. Oxford Lab has been monitoring and studying the recent outbreak of fish lesions and mortalities in Chesapeake Bay. The Great Lakes Environmental Research Laboratory (GLERL) conducts research on the status and causes of eutrophication, which can lead to HABs in coastal ecosystems, and the recent occurrence of HABs in the Great Lakes. Highlights include long-term nutrient dynamics and modeling studies on key Great Lakes ecosystems and video documentation of zebra mussel ability to selectively feed on nontoxic algal cells while rejecting toxic HAB cells. GLERL investigators participate in HAB-related re-

Figure 10. *NOAA's Charleston Laboratory scientist identifies HABs.*

search in the Gulf of Mexico (e.g., nutrient inputs to the Gulf of Mexico from the Mississippi outflow and the relationship to hypoxia) and are also involved in the ECOHAB: Florida project in the Gulf of Mexico (e.g., determining the autecology of *G. breve*). Northwest Fisheries Science Center biotoxin research is focused and integrates methodology, food web interactions, species susceptibility and coastal ecosystem health. Recent highlights include development of new receptor bindings and DNA probes for toxin and toxic algae detection, studies of toxin transfer through the food web, and culture studies to determine effects of nutrients on toxin production.

EPA

U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD) is presently cooperating with NOAA and others in supporting research concerning toxic algal blooms as one of the cosponsors of the ECOHAB Program.

Figure 11. *EMAP scientists test water quality in U.S. estuaries.*

Further, EPA has been NOAA's primary partner in responding to recent White House and Congressional requests for HAB activities, exemplified by the EPA/NOAA partnership in allocating $500,000 in the summer of 1997 for rapid response to fish lesions and mortalities, and public health concerns linked to *Pfiesteria* in the Chesapeake. Further, EPA and NOAA led the effort to draft the *National Strategy* and distribute FY98 funds for State monitoring and assessment programs for HABs. In 1997, EPA also provided funds to North Carolina to establish a rapid response team. Additionally, EPA's Environmental Monitoring and Assessment Program (EMAP) and NOAA's National Status and Trends Program have developed and tested appropriate methods to characterize the condition of the Nation's resources, including those related to HABs.

The National Health and Environmental Effects Research Laboratory (NHEERL) Gulf Ecology Division (GED) has recently established a new multidisciplinary HAB research team with objectives for FY98 that include 1) establishing a state-of-the-art HAB Experimental Culture Exposure Facility and 2) developing rapid response and monitoring capabilities for HAB events in the Gulf of Mexico. The HAB team will collaborate with the GED's Coastal Eutrophication Team to better define and understand the suggested causative link between increased nutrient loading and HAB phenomena. Recently, a Harmful Algal Bloom page was added to the Gulf of Mexico Aquatic Mortality Response Network (GMNET) at http://pelican.gmpo.gov/gmnet/gmhome.html). Finally, GED is working to obtain funding for a proposed study of HAB formation and transport in the Gulf of Mexico.

ORD will be involved in assessing the possible adverse effects of specific toxins on laboratory rodents and to evaluate the neurological effects of *Pfiesteria* toxins on North Carolina watermen. ORD also proposes to conduct studies to assess the efficacy of its screening methodologies in evaluating the potential neurotoxicity to HAB toxins to aquatic animals.

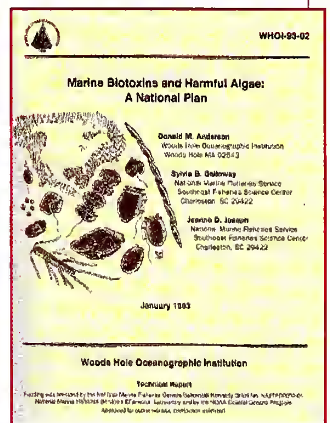
EPA's Office of Water. Many of the programs in the Office of Water address nonpoint sources of pollution that have been implicated as causes for many HAB events. The National Estuary Program (NEP) includes 28 estuaries around the country. All 28 estuaries have characterized nutrient over-enrichment problems and several have identified HABs as priority concerns. In fact, the Albemarle-Pamlico Sound Estuary Program was the site of the discovery of *Pfiesteria*. EPA's National Nutrient Strategy is being completed to strengthen our ability to assess and control nutrient over-enrichment in the

nation's waters. This strategy summarizes the direction the EPA recommends with respect to developing water quality criteria to address over-enrichment problems. Concentrated Animal Feeding Operations (CAFO) is an EPA regulatory program whose aim is to ensure that discharges from large feeding operations have National Pollutant Discharge Elimination System (NPDES) permits. It is anticipated that the program will support the development and promotion of improved methods to dispose of animal waste.

The Total Maximum Daily Load (TMDL) program addresses waterbodies listed by States as impaired and for which pollution controls are not stringent enough to achieve water quality standards applicable to such waters. Under the TMDL program we can identify which rivers or estuaries are listed by the States as impaired due to nutrients or other HAB indicators and whether a TMDL has been established to adequately reduce the nutrient loadings from all sources. The Tri-chemical Action Plan includes several recent and pending air regulations which will reduce air emissions (and deposition) of various forms of nitrogen as well as propose additional actions that should be taken to further reduce nitrogen loadings from air emissions, other nonpoint sources, and wastewater discharges. Under the Clean Water Act §319 Nonpoint Source Management Programs, EPA provides funding, guidance and technical assistance to States in their efforts to minimize nutrients, from nonpoint sources. Beaches Environmental Assessment Closure and Health (B.E.A.C.H.) is an initiative to improve the safety of recreational waters in the U.S. through improved public right to know about the quality of swimming waters; development of appropriate warning systems and improved monitoring strategies for fresh water and marine/estuarine beach scenarios.

NSF

National Science Foundation (NSF) is concerned with developing basic scientific understanding of the direct and indirect causes of HABs and their ecological consequences through research on the physiological and ecological basis of bloom formation, the physical and chemical attributes of coastal oceans that facilitate them, the population attributes of bloom species, and the long-term consequences of ecosystem changes. NSF cosponsored the report *ECOHAB The ecology and oceanography of harmful algal blooms a national research agenda* and continues to cooperate with NOAA by providing funding for the ECOHAB Program through the NSF Division of Ocean Sciences, Biological Oceanography Program. The Biological Oceanography Program also supports other HAB-related research as part of its regular research program. In addition, the NSF Division of Biological Infrastructure and the Biological Oceanography provide support for the Provasoli-Guillard National Center for Culture of Marine Phytoplankton (CCMP), a repository for phytoplankton cultures including HAB species.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Marine Biotoxins and Harmful Algae:
A National Plan

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Woods Hole Oceanographic Institution

Technical Report

Figure 12. *The National Plan is the basis for a U.S. HAB program.*

DOD-ONR

Office of Naval Research (ONR) supports research related to the mission of the U.S. Navy and to develop improved understanding of the environment (e.g., optical properties of surface waters) in which the Navy must operate. As part of this research, ONR has been cooperating with NOAA and others in providing support for the ECOHAB Program.

NASA

National Aeronautics and Space Administration (NASA) has recently become

an advisor to ECOHAB because of its strong commitment and interest to remote detection of surface pigment, as found in some HABs. With the successful orbiting and operation of SeaWifs and long-term commitment to determining surface distributions of phytoplankton biomass and productivity in space and time, NASA's partnership is timely and beneficial to the national HAB effort.

DOI-USGS

U.S. Geological Survey (USGS), as part of its contribution to the Chesapeake Bay Program, is conducting field sampling, laboratory analyses and building a Geographical Information System data base on the relationship between nutrient inputs in the watershed and Chesapeake Bay water quality. USGS's Biological Resources Division has begun investigations to determine factors contributing to fish lesions (e.g., the complex of *Pfiestera*-like organisms) in selected tributaries of the Chesapeake Bay. Scientists from the USGS Center for Marine and Coastal Geology in Woods Hole, MA, are actively involved in the ECOHAB-Gulf of Maine regional study, providing mooring equipment and expertise, and developing coupled physical/biological models of *Alexandrium* dynamics in the large region between the Canadian border and Massachusetts.

HHS-CDC

Centers for Disease Control and Prevention (CDC), as the Nation's disease prevention agency, has a monitoring, advisory and public communication role regarding human health concerns and harmful algal blooms. As an example, CDC recently collaborated with officials from state health departments (i.e., Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, West Virginia, Virginia and the District of Columbia) and held a September 1997 *Workshop on the Public Health Response to Pfiesteria*. The CDC brought together representatives of state health departments and the relevant federal agencies (e.g., Food and Drug Administration, National Institute of Environmental Health Sciences, U.S. Environmental Protection Agency) with the goal of planning a coordinated, comprehensive multi-state public health program to provide scientifically valid information on health effects of *Pfiesteria* exposure. The recent Congressional allocation of $10 million will provide funds necessary for state-specific surveys to be implemented and compiled for detailing symptoms of HAB exposures.

Figure 13. *This CDC scientist is isolating HAB toxins in human tissues.*

NIH-NIEHS

National Institute of Environmental Health Sciences (NIEHS) addresses potential human health impacts of *Pfiesteria* and other HABs through response, research, and prevention. NIEHS responded immediately to the public health threat posed by *Pfiesteria* by assisting state health departments in their efforts to address this problem and by enabling scientists to interact more effectively. NIEHS research includes both basic studies to identify and characterize relevant toxins and their associated biological effects as well as clinical and epidemiological research to define more accurately exposure and health effects. NIEHS prevention efforts include support of assay development for improved identification and early detection and monitoring of the organism and toxin.

In August 1997, NIEHS received a request from Senators Mikulski and Sarbanes to help investigate fish kills in the Pocomoke River of southeastern Maryland. Representatives from NIEHS and CDC, visited the a workshop on "Hazardous Marine/Freshwater Microbes and Toxins," where researchers, regulators, federal representatives, and state health and

environmental officials met and discussed their current understanding of a variety of hazardous toxins. This workshop was the first that enabled *Pfiesteria* and other marine toxin researchers to meet, exchange information, and identify research gaps.

As part of its Center Program, NIEHS supports a network of Marine and Freshwater Biomedical Sciences (MFBS) Centers across the country. Two of these are active in the area of *Pfiesteria* and HAB research. The University of Miami MFBS Center, long noted for its work in marine toxins, is engaged in isolating and characterizing *Pfiesteria* toxins. The Duke University MFBS Center has focused on understanding possible biological effects arising from exposure to *Pfiesteria*-laden waters.

The NIEHS intramural program has provided assistance to scientists from North Carolina State University, NOAA National Marine Fisheries Service in Charleston, South Carolina, and NIEHS to collaborate on isolating *Pfiesteria* toxin.

To stimulate prevention research, NIEHS recently awarded $400,000 to a consortium composed of leading investigators in both basic and clinical research related to *Pfiesteria*. This award will bring together researchers at the NIEHS MFBS Center at the University of Miami, headed by Dan Baden, Ph.D., and at the University of Maryland School of Medicine, headed by Glenn Morris, M.D., M.P.H., to examine the potential public health impact of this organism collaboratively. This project plans to purify and characterize toxins, examine their effects in model systems, develop a genetic assay for identification and detection of *Pfiesteria*, obtain information on risk factors and exposure levels for human health effects, and clarify putative neurologic effects. This multidisciplinary approach is an integrated effort to examine systematically the key research questions that must be answered in order to improve our understanding of both the environmental and public health consequences of *Pfiesteria*. Results from this and related research will lead to development of diagnostic, therapeutic, and preventative strategies.

Figure 14. *This NIEHS scientist centrifuges HAB cells for toxicology studies.*

FDA

Food and Drug Administration (FDA) is responsible for ensuring safe seafood for consumption and, therefore, has well-established programs of research, management, and public information regarding HABs as they relate to toxicity in seafood. There are ongoing research programs dealing with PSP, NSP, ASP, DSP, and ciguatera. Prior to 1997, the possibility that *Pfiesteria* had seafood safety implications was being addressed by closely following research being done in other laboratories. With the dramatic intensification of this issue, research has been started in-house with collaboration from other laboratories to clarify whether or not toxins from *Pfiesteria* can accumulate in seafood and cause illness in human consumers. In general, FDA research laboratories culture toxic marine organisms, then isolate and characterize the toxins they produce. With a continuing supply of the toxins thus assured, FDA labs develop detection methods for the toxins and examine their toxicity to provide a basis for regulatory policy. FDA researchers also address the broader issue of effective management strategy, and are currently exploring the utility of networks of field observers who take phytoplankton samples and gather relevant environmental information. Such networks are now in place with FDA coordination in California, Maine, and Massachusetts, and show great promise as a strategy for reducing the cost and improving the reliability of marine biotoxin monitoring programs.

Figure 15. *FDA-trained volunteers check plankton samples for HABs.*

The FDA supports established monitoring programs worldwide through the production and distribution of reference standards, expert assistance, and quality assurance checks of laboratories. Marine biotoxin monitoring in the U.S. is conducted primarily through cooperative programs with the states under the guidance of the FDA. The FDA provides public information and education through its Seafood Hotline telephone service, a web page that includes discussion of marine biotoxin issues, and tradition channels such as the print media and public information specialists.

USDA

U.S. Department of Agriculture (USDA). The strong linkages between land-use, nutrient loads and watershed conditions are major concerns for this agency (Figure 16) and have led to USDA's advisory role in ECOHAB. There is an intensive watershed assessment program, providing water quality data critical for HAB prediction. Future efforts will identify agricultural activities likely favoring HAB expression, leading to application of best management practices (BMPs) for these critical activities.

NOPP

National Ocean Partnership Program (NOPP). This congressionally mandated partnership of 12 federal agencies promotes its goals of assuring national security, advancing economic development, protecting quality of life, and strengthening science education and communication through improved knowledge of the ocean by coordinating and strengthening partnerships among Federal agencies, academia, industry, and other members of the oceanographic scientific community. Regarding HAB problems, NOPP recently supported a 2-year project, *Gulf of Mexico Ocean Monitoring System*, to generate continual surface ocean current velocities in the Gulf. This effort, a collaboration between the Dynalysis Corporation, several Federal agencies and the university research community, will generate critically needed surface current distributions that are likely responsible for distributing *G. breve*, a toxic HAB that has plagued local coastal resources, economies, and public health in Florida and the northern Gulf States, along the coastline of the southern United States.

Figure 16. *USDA scientists study land-use links to HABs and advise farmers on nutrient abatement measures.*

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We are pleased to thank the following contributors for their high quality and expressive photographs on various aspects of U.S. HABs. Without their contributed body of work, we could hardly have prepared such a striking format to help us draw public attention to this subject of national concern. The authors on behalf of their federal agencies thank you one and all.

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EXECUTIVE SUMMARY

This document was prepared in response to a request by the House Committee on Appropriations. In its *Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations Bill, Fiscal Year 1998*, the Committee "urged NOAA's Coastal Ocean Program to continue its efforts to establish a National Harmful Bloom program that will expand the current geographic scope of studies on the ecology and oceanography of harmful algal blooms (ECOHAB) to additional geographic areas and conduct research on the means to prevent, control, and mitigate blooms and their effects." Because the Department of Commerce (DOC) efforts through the National Oceanic and Atmospheric Administration (NOAA) are cooperative with other Federal agencies, the Committee requested a report "outlining interagency efforts and progress." Here is that report.

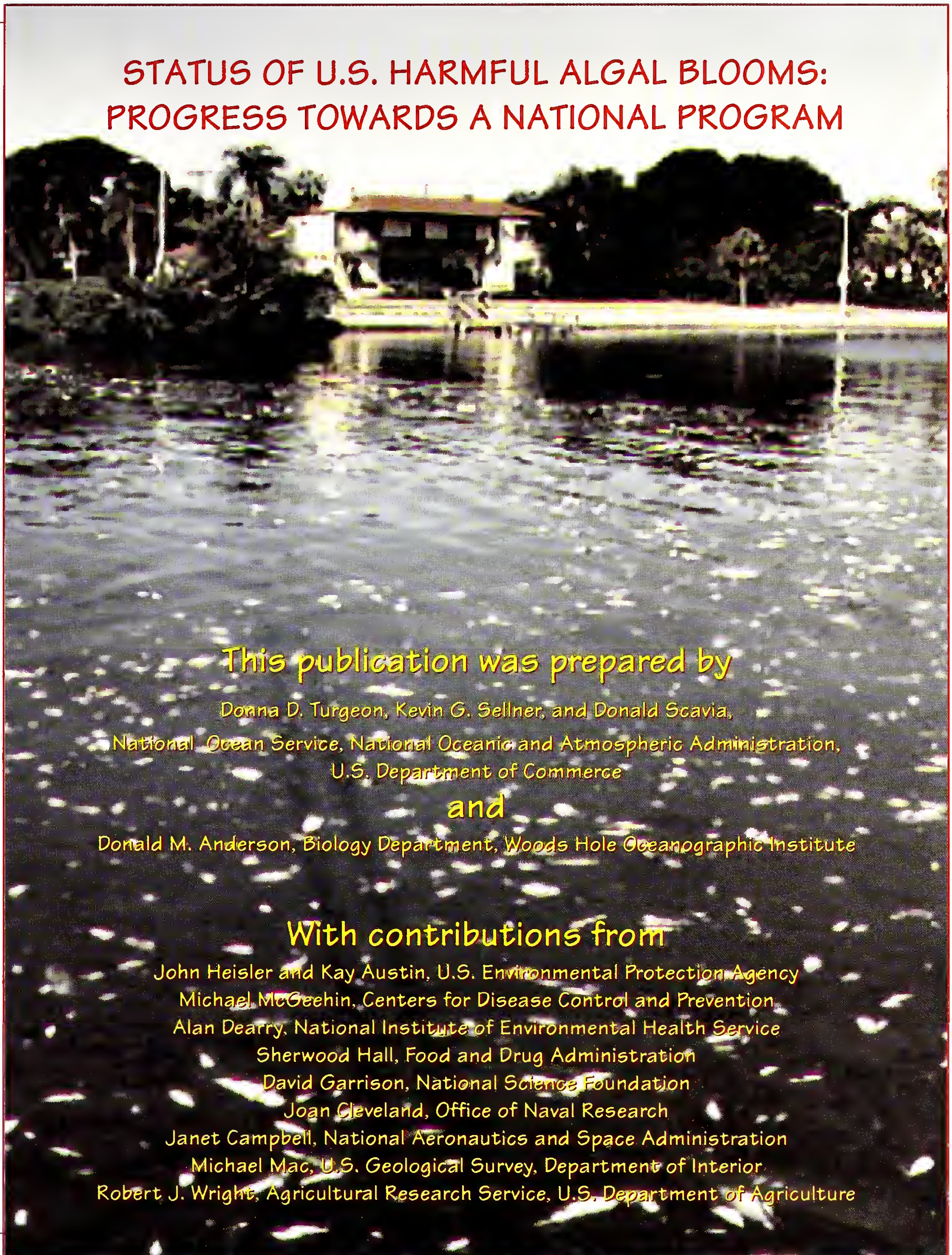
Harmful algal blooms are an increasing worldwide threat with significant impacts on U.S. coastal regions. A harmful algal bloom (HAB) in local waters can have serious consequences, depending on the species, that range from killing fish and other wildlife to making shellfish poisonous and perhaps deadly to consumers. Recently, blooms have occurred in new coastal areas and new species have also appeared, catching watermen, residents, and local officials off-guard (e.g., "*Pfiesteria* hysteria" in mid-Atlantic coastal waters).

Massive mortalities of wild fish due to coastal HABs.

Severe economic losses of farmed fish due to HABs.

About five years ago, DOC/NOAA supported a workshop that resulted in a National Plan (*Marine Biotoxins and Harmful Algae: A National Plan*) and set in place a process that would eventually evolve into an interagency national program to understand and ameliorate the impacts of coastal HABs. DOC/NOAA and the National Science Foundation (NSF) sponsored a second report (*ECOHAB: The Ecology and Oceanography of Harmful Algal Blooms a National Research Agenda*). This National Research Agenda is the blueprint for ECOHAB, the first Federal research program on the ecology and oceanography of HABs. ECOHAB research is currently supported by the DOC/NOAA, NSF, the U.S. Environmental Protection Agency, the Office of Naval Research, National Aeronautics and Space Administration, and the U.S. Department of Agriculture. Recently, DOC/NOAA and the National Fish and Wildlife Foundation sponsored the development of a third strategic report (*Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control, and Mitigation*), blue-printing needs for a national management strategy for HABs. The *Ad Hoc* Interagency Task Force on Marine Biotoxins and Harmful Algae, comprised of agency representatives and academic researchers, guides, directs, and supports the U.S. HAB program. The National Office of Marine Biotoxins and Harmful Algal Blooms in Woods Hole, Massachusetts, distributes HAB information and assists the national effort. This report summarizes the status of U.S. coastal HABs, collective federal HAB efforts, and outlines interagency U.S. cooperation to better guide HAB research, prevention, control, and mitigation.

STATUS OF U.S. HARMFUL ALGAL BLOOMS: PROGRESS TOWARDS A NATIONAL PROGRAM



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